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(54) Abstract Title
Sub-terrain object detector

(57) A sub-terrain object detector 10 comprises a sound source 11 arranged to generate sound vibrations 12, which are transmitted through a terrain area 13 and a laser vibrometer system 14.

The sound source 11 includes an electromagnetic vibrator 15 and is arranged to generate sound vibrations 12 which travel through the terrain area 13 and are reflected by any sub-terrain objects 16 to generate sound reflection vibrations 17 which make their way to the surface 18 where they interfere with sound vibrations 12 to create an acoustic interference pattern 19 on the surface 18.

The laser vibrometer system 14 has a transmitter 20 and a receiver 21 connected to a phase detector 22. The transmitter 20 generates a beam 23 which is steered to a sequence of surface positions 24 to illuminate the surface 18. Light from the beam 23 incident on each surface position 24 is scatted to produce a resultant signal 25 which is received at receiver 21. Phase modulation of the resultant signal 25, produced by the acoustic interference pattern 19, is detected by the phase detector 22 and recorded to build up a map of the phase differences against the surface positions 24.

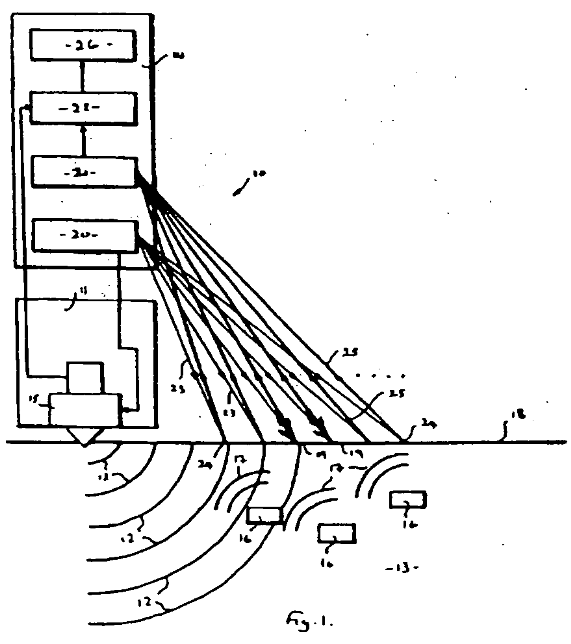

Fig. 1.

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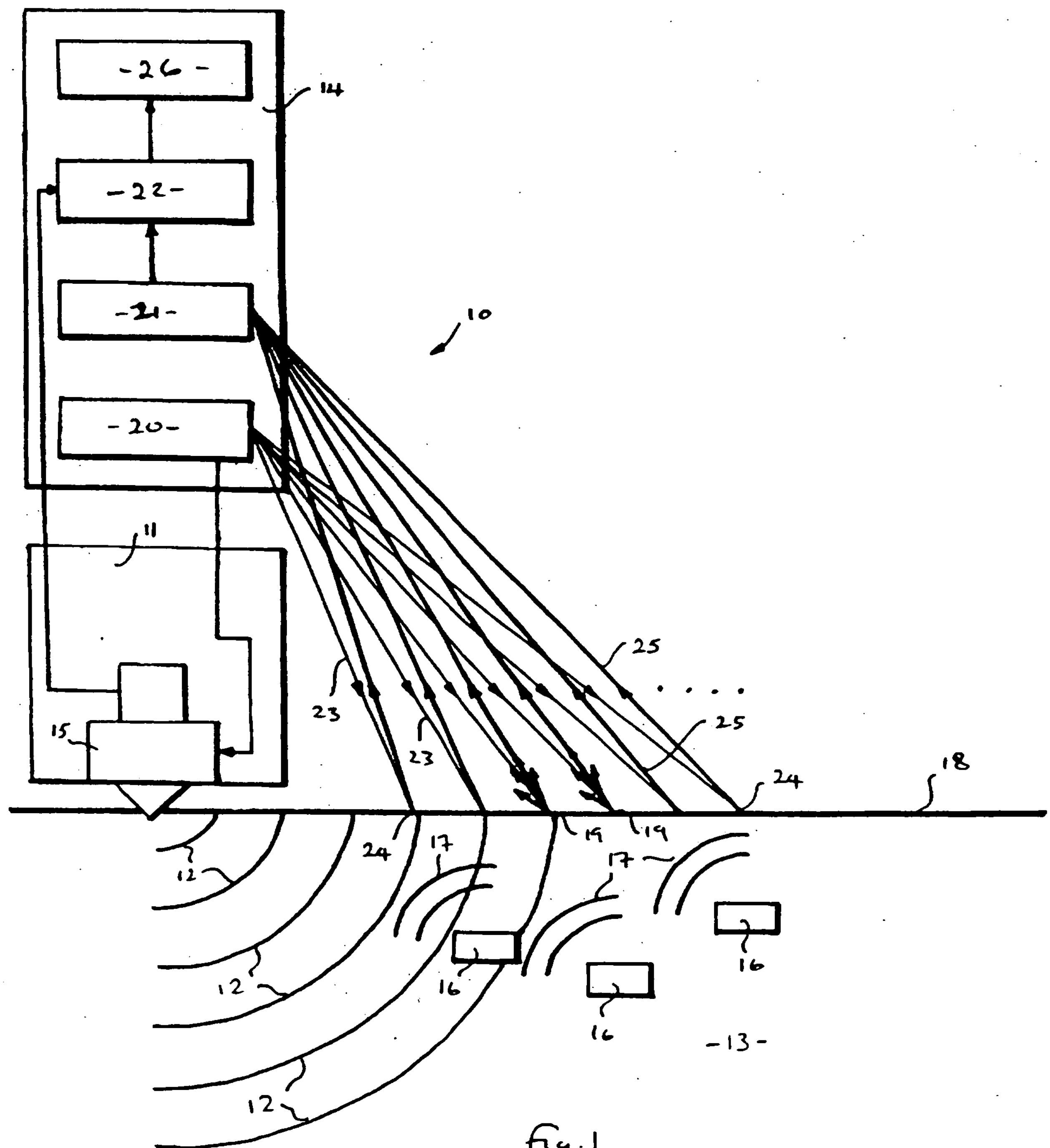

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Fig. 1.

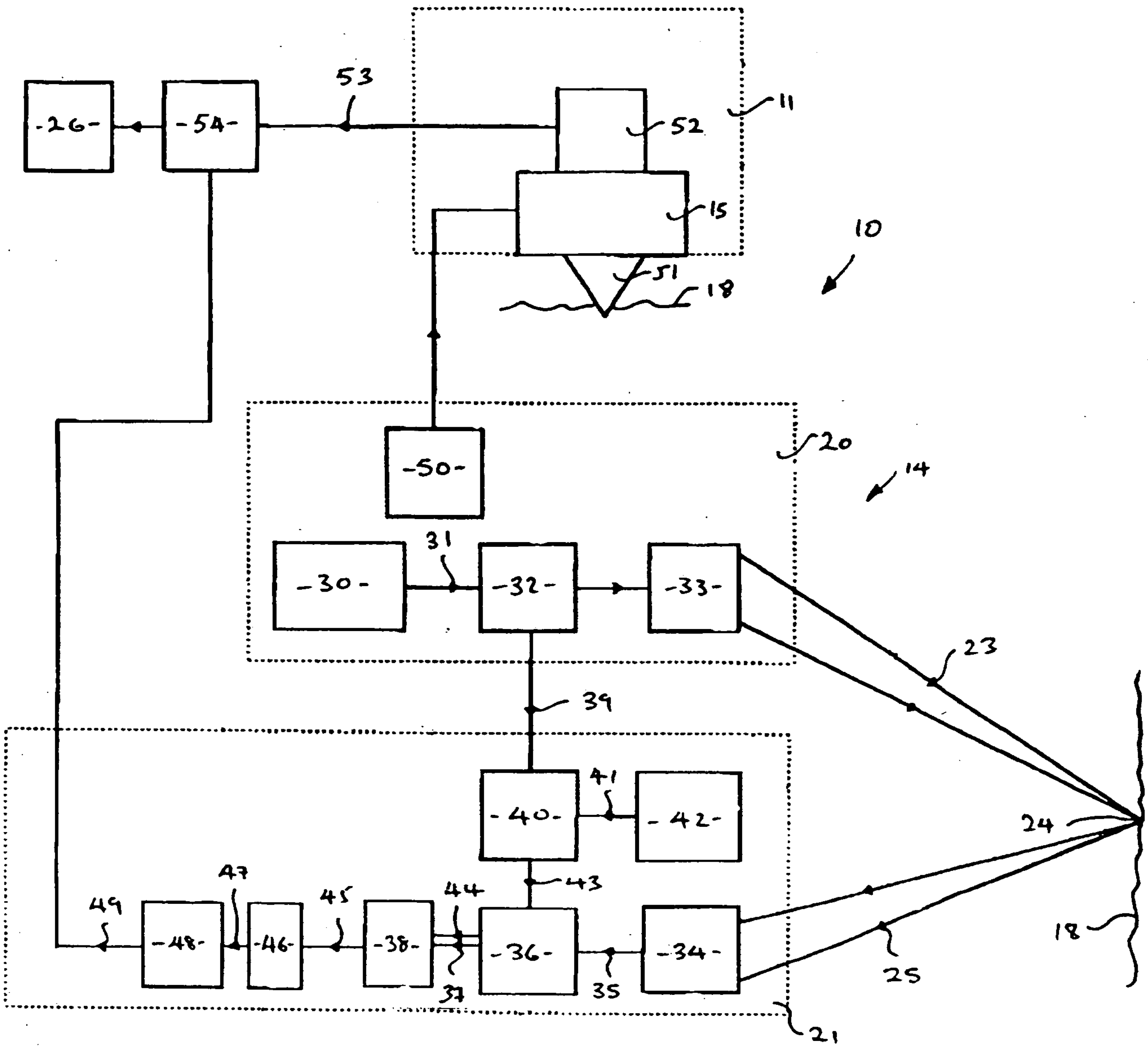
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fig. 2.

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IMPROVEMENTS IN OR RELATING TO THE DETECTION OF SUB-TERRAIN OBJECTS

This invention relates to sub-terrain object detector and to a method of detecting sub-terrain objects. The invention finds particular application in the detection of mines which may be formed from metal or plastic material.

The detection and accurate location of buried land mines is an urgent requirement in war zones where they pose a high risk of death and injury to civilians and personnel. Small plastic anti-personnel mines are particularly difficult to reliably detect and a great number of these devices have been distributed around the world. Existing detection techniques using ground penetrating radar or thermal detection have poor sensitivity when used to locate plastic type mines as there is only a small difference between the dielectric and thermal properties of the plastic type mine and those of the surrounding ground.

Generally, existing acoustic methods for detecting buried objects involve exciting sound vibrations in the ground with a electromagnetic transducer and detecting the field pattern of acoustic waves at various points with an array of receivers. Buried objects such as mines reflect sound from their surfaces thereby generating an acoustic interference pattern which is detectable by measuring the phase and/or amplitude of the pattern from the array of receivers. However, planting an array of discrete receivers in a minefield is time consuming and hazardous to personnel.

It is an objection of the present invention to obviate or mitigate disadvantages associated with the prior art.

According to a first aspect of the present invention a sub-terrain object detector comprises a sound source operably arranged to transmit sound vibrations into a terrain area, a transmitter operably arranged to focus a beam onto a surface of the terrain area, a receiver operably arranged to receive a resultant signal backscattered from the beam caused by sound vibrations substantially on the surface, and a detector operably arranged to determine the presence of a sub-terrain object by comparison of the resultant signal with a characteristic pattern indicative of the presence or absence of a sub-terrain object below the surface of the terrain area.

In this manner the presence of a sub-terrain object can be detected without the need to deploy discrete receivers in the terrain area. This is particularly advantageous when the sub-terrain objects are mines.

The transmitter may be operably arranged to direct the beam to a sequence of positions on the surface, the receiver may be operably arranged to receive the resultant signal for each beam position and the detector may be operably arranged to determine the presence of each sub-terrain object by comparison of each resultant signal with a characteristic pattern indicative of a sub-terrain object.

Preferably, the sound source may be an electro-magnetic or piezoelectric transducer. The sound source may also comprise an accelerometer which may be carried by the transducer, the accelerometer may be operably arranged to provide a reference signal corresponding to

movement of the transducer and the detector may be operably arranged to compare the reference signal with the resultant signal.

Alternatively, the sound source may be a projectile which is propelled into the terrain area and which is arranged to produce sound vibrations in response to a received signal.

In a further alternative, the sound source may be a gun operably arranged to fire pellets into the terrain area to produce sound vibrations when the pellets impact the surface of the terrain area or the sound source may be a focussed laser beam operably arranged to transmit energy pulses into the terrain area to produce sound vibrations by ablation of the surface of the terrain area. A sensor may be operably arranged to provide a reference signal corresponding to activation of the sound source and the detector may be operably arranged to compare the reference signal with the resultant signal.

The transmitter, receiver and detector may be located in a position remote from the sub-terrain objects. The detector may be operably arranged to determine the amplitude and phase of the resultant signal. Preferably, the transmitter and receiver may be operably arranged to form a laser vibrometer system.

According to a second aspect of the present invention a method of detecting sub-terrain objects comprises transmitting sound vibrations into a terrain area, focussing a beam onto a surface of the terrain area, receiving a resultant signal backscattered from the beam near the surface caused by sound vibration substantially on the surface, and determining the presence of a sub-terrain object by comparison of the resultant signal with a characteristic pattern indicative of the

presence or absence of a sub-terrain object below the surface of the terrain area.

The invention is now described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram which illustrates the present invention, and

Figure 2 is a more detailed block diagram of Figure 1.

In Figure 1, a sub-terrain object detector 10 generally comprises a sound source 11 arranged to generate sound vibrations 12, whether in the audible range or not, which are transmitted through a terrain area 13 and a laser vibrometer system 14.

The sound source 11 comprises an electromagnetic vibrator 15 to which is applied low audio frequencies at a few watts power to generate sound vibrations 12 having a sound amplitude of several micro metres that can be detected. The sound vibrations 12 travel through the terrain area 13 and are reflected by any sub-terrain object 16 to generate sound reflection vibrations 17 which make their way to a surface 18 where they interfere with sound vibrations 12 to create an acoustic interference pattern 19 substantially on the surface 18.

The detector 10 operates equally well with plastic or metal type sub-terrain objects 16 as sound reflection vibrations 17 are dependent on the stiffness and density of the sub-terrain object 16 relative to the surrounding terrain area 13.

The laser vibrometer system 14 comprises a transmitter 20 and a receiver 21 operably connected to a phase detector 22. The transmitter 20 comprises a single frequency laser arranged to generate a beam 23 which is steered to a sequence of surface positions 24 to illuminate the surface 18. Light from the beam 23 incident on each surface position 24 is scattered to produce a resultant signal 25.

Some of the resultant signal 25 is received at the receiver 21 which is a coherent receiver. Phase modulation of the resultant signal 25 produced by the acoustic interference pattern 19 is detected by the phase detector 22 as a phase modulation of the receiver 21 output. The phase modulation can be recorded by a computer 26. Since light has a short wavelength and the coherent receiver 21 is highly sensitive, extremely small vibration amplitudes can be detected at each surface position 24.

The sub-terrain detector 10 and laser vibrometer system 14 are described in more detail by reference to Figure 2, wherein like reference have been used to indicate similar integers to those illustrated in Figure 1. In Figure 2, the transmitter 20 comprises a laser 30 which is preferably a neodymium-YAG ring laser producing a single-frequency output beam 31 having a narrow spectral width, typically 10kHz. This passes through a beamsplitter 32 and a telescope 33 to form the beam 23, which is preferably 20 to 50 mm in diameter. The beam 23 is focused at each surface position 24 where vibration measurements are to be made, and is preferably at a distance between 10 to 100 metres from the laser vibrometer system 14.

The beam 23, which is randomly scattered at each surface position 24 produces the resultant signal 25 that a enters telescope 34, contained within the receiver 21 which is associated with

the transmitter 19, where it is focused into a collimated beam 35. The beam 35 passes through a beamsplitter 36 to form a beam 37 which is then incident on the surface of a photodetector 38. The photodetector 38 is preferably an indium-gallium-arscnide photodiode which is sensitive to the near infrared wavelength produced by the laser 30.

A small proportion of light produced by the laser 30, typically 1%, is diverted by the beamsplitter 32 to form a beam 39 which passes through an acousto-optic cell 40 where it is changed in frequency by an amount typically between 10MHz and 150MHz by a radio frequency drive signal 41 supplied by a constant frequency signal generator 42. A frequency shifted beam 43 emerges from the acousto-optic cell 40 and is diverted by beamsplitter 36 to form a reference beam 44 which is also incident on the photodetector 38 at the same position as the beam 37. The position and orientation of the beamsplitter 36 are adjusted so that the reference beam 44 is parallel to, and collinear with, the beam 37.

An alternating current is therefore produced in the photodetector 38 by optical interference between beams 37 and 44. A current output 45 from the photodetector 38 has substantially the same frequency as the radio frequency drive signal 41 supplied by signal generator 42, but is phase-modulated by any vibration of surface 18 at each surface position 24.

Vibration at each surface position 24 of half the wavelength of the laser 30, typically 0.5 micrometers, produces a phase shift of 2π in the current output 45. The current output 45 is amplified by amplifier 46 and a resultant amplified signal 47 passes to a frequency discriminator 48, which produces an output signal 49 having a voltage proportional to the rate of change of phase of the current output 45. This is proportional to the surface velocity at each surface

position 24, so it provides a measure of the sound vibration amplitude present at each surface position 24. Provided that the magnitude of the resultant signal 25 received by the receiver 21 is sufficient, such that the current output 45 has a large signal to noise ratio, the output signal 49 will have a random noise level equivalent to the vibration at each surface position 24 with an amplitude typically less than 1 nanometer when operating at a range of 100 metres or less.

The transmitter 20 also comprises an audio frequency oscillator 50, typically operating at a fixed frequency between 100 and 500Hz, which drives the electromagnetic vibrator 15 contained within the sound source 11. The vibrator 15 has a metal spike 51 attached to it which penetrates the surface 18 and transmits sound vibrations in the terrain area 13 at the drive frequency of oscillator 50. An accelerometer 52 is attached to the moving armature of the vibrator 15, giving an output signal 53 having a voltage proportional to the vibration amplitude applied to the terrain area 13. The output signal 53 is applied to one input port of a phasemeter 54, while another input port receives the output signal 49 from the laser vibrometer system 14. The phase difference between signals 49 and 53 is measured by the phasemeter 54 and is recorded by the computer 26.

In operation, the laser beam 23 is directed to a sequence of surface positions 24, as shown in Figure 1, and phase difference readings from each surface position 24 are recorded by the computer 26.

The computer 26 then produces a two-dimensional map, not illustrated, of the phase differences against the surface positions 24. If the terrain area 13 is homogeneous and contains no sub-terrain objects 16, then sound vibrations from the vibrator 15 will travel at a uniform velocity

in a radial direction from the vibrator 15. The map of phase differences produced by the computer 26 will therefore show the phase difference increasing linearly with radial distance from the vibrator 15. If a sub-terrain object 16, such as a plastic mine, is located a small distance below the surface 18 it will scatter a proportion of the sound vibration energy to produce reflection vibrations 17, which will interfere with the remaining unscattered generated sound vibration 12 to produce an interference pattern 19 on the surface 18. The interference pattern 19 will in general have a different phase to that which would be measured if there were no sub-terrain object 16 present, such that the phase map produced by the computer 26 would show nonlinear phase variations, particularly in the immediate vicinity of any sub-terrain object 16. If the computer 26 is programmed to show the phase gradiant rather than the phase itself in a radial direction from the vibrator 15, its value will be substantially zero at all points, except where a sub-terrain object 16 is present. In the vicinity of a sub-terrain object 16 the phase gradient comprises a ring structure containing alternately positive and negative values, with the centre of the ring located above the position of the sub-terrain object 16. Inspection of the phase gradient map therefore immediately shows the positions of such sub-terrain objects 16.

It will be understood that the transmitter 20 and receiver 21 could be integrated using a suitable optical arrangement.

When the sub-terrain object 16 to be located is a mine, the sound source 11 can be a small battery power vibrator 15 which can be formed as a projectile that can be propelled to a position ahead of the sub-terrain object detector 10 using a catapult or another suitable device. The sound source 11 can then be used to produce sound vibrations 12 in response to a signal received from the oscillator 50. The sound source 11 can then be recovered after the terrain area

13 has been tested.

Alternatively, the sound source 11 could be provided by a gun firing pellets into the surface 18 or by a focussed laser beam producing high energy pulses, for example from a welding laser, to cause explosive evaporation of water in the terrain area 13 thereby generating sound vibrations 12. For example, this could be a pulsed Holmium-YAG laser, producing a wavelength of 2.1 micrometers which is strongly absorbed by water. The broad acoustic spectrum from the laser pulses could be used in conjunction with fast Fourier transform processing of the vibrometer system 14 output to generate a phase and/or amplitude spectrum as required.

The problem of vegetation screening the beam from direct contact with the surface 18 of the terrain area 13 when a measurement is made can be remedied by using a high powered laser, not illustrated, co-boresighted with the beam 23 to burn a hole through the vegetation to expose the surface 18 beneath. Although signals are still detectable without burning a hole through the vegetation, vegetation tends to attenuate the higher acoustic frequencies giving erroneous phase and/or amplitude results. A high powered laser diode array with beam focussing optical elements could also be used to provide sufficient power to ablate ground vegetation. Alternatively a CO_2 or Nd:YAG laser arrangement could be used.

CLAIMS

1. A sub-terrain object detector, comprising

a sound source operably arranged to transmit sound vibrations in a terrain area,

a transmitter operably arranged to focus a beam onto a surface of the terrain area,

a receiver operably arranged to receive a resultant signal backscattered from the beam caused by sound vibrations substantially on the surface, and

a detector operably arranged to determine the presence of a sub-terrain object by comparison of the resultant signal with a characteristic pattern indicative of the presence or absence of a sub-terrain object below the surface of the terrain area.

2. A sub-terrain object detector, as in Claim 1, wherein the transmitter is operably arranged to direct the beam to a sequence of positions on the surface, the receiver is operably arranged to receive the resultant signal for each beam position and the detector is operably arranged to determine the presence of each sub-terrain object by comparison of each resultant signal with a characteristic pattern indicative of a sub-terrain object.

3. A sub-terrain object detector, as in Claims 1 or 2, wherein the sound source is an electro-magnetic transducer.

4. A sub-terrain object detector, as in Claims 1 or 2, wherein the sound source is a piezoelectric transducer.

5. A sub-terrain object detector, as in Claims 3 or 4, wherein the sound source also comprises an accelerometer which is carried by the transducer, the accelerometer being operably arranged to provide a reference signal corresponding to movement of the transducer and the detector is operably arranged to compare the reference signal with the resultant signal.

6. A sub-terrain object detector, as in Claims 1 to 5, wherein the sound source is a projectile which is propelled into the terrain area, and which is arranged to produce sound vibrations in response to a received signal.

7. A sub-terrain object detector, as in Claims 1 or 2, wherein the sound source is a gun operably arranged to fire pellets into the terrain area to produce sound vibrations when the pellets impact the surface of the terrain area.

8. A sub-terrain object detector, as in Claims 1 or 2, wherein the sound source is a focussed laser beam operably arranged to transmit energy pulses into the terrain area to produce sound vibrations by ablation of the surface of the terrain area.

9. A sub-terrain object detector, as in Claims 7 or 8, wherein a sensor is operably arranged to provide a reference signal corresponding to activation of the sound source and the detector is operably arranged to compare the reference signal with the resultant signal.

10. A sub-terrain object detector, as in any preceding claim, wherein the transmitter, receiver and detector are located in a position remote from the sub-terrain objects.

11. A sub-terrain object detector, as in any preceding claim, wherein the detector is operably arranged to determine the amplitude and phase of the resultant signal.

12. A sub-terrain object detector, as in any preceding claim, wherein the transmitter and receiver are operably arranged to form a laser vibrometer system.

13. A sub-terrain object detector substantially as described with reference to the accompanying drawing.

14. A method of detecting sub-terrain objects, comprising

transmitting sound vibrations into a terrain area,

focussing a beam onto a surface of the terrain area,

receiving a resultant signal backscattered from the beam caused by vibrations substantially on the surface, and

determining the presence of a sub-terrain object by comparison of the resultant signal with a characteristic pattern indicative of the presence or absence of a sub-terrain object

below the surface of the terrain area.

15. A method of detecting sub-terrain objects substantially as described with reference to the accompanying drawing.

Application No: GB 9905261.5
Claims searched: 1-15
Examiner: Frank Moeschler
Date of search: 26 May 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1G (GEV, GMC, GPE)

Int Cl (Ed.6): G01S-15/02, 15/04; G01V-1/00, 1/16, 11/00; G10K-15/04

Other: Online: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	WO 99/10755 A2 (NORTHEASTERN UNIVERSITY) See Page 3 lines 34-36	1-12,14

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		